VEHICLE SYSTEMS PANEL

INTRODUCTION

PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

- NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS

- TODAY'S INVESTMENT
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES

- TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
  - SELECTED EXAMPLES (8090, 2219, 7XXX)
VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- MATERIALS DEVELOPMENT
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION

- MANUFACTURING TECHNOLOGY
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING

- NDE
EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS:</th>
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<tbody>
<tr>
<td>• ADVANCED STRUCTURAL MATERIALS</td>
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<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
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<tbody>
<tr>
<td>• IN THE LAST 10 YEARS, MANY NOVEL MATERIALS HAVE BEEN DISCOVERED THAT HAVE APPLICABILITY TO SPACE PROGRAMS</td>
<td>• EVALUATE THE APPLICATION AREAS AND STATE OF MATURITY OF THESE NEW MATERIALS</td>
</tr>
<tr>
<td>• THESE INCLUDE BUT ARE NOT LIMITED TO:</td>
<td>• DESIGN AND ANALYTICAL TOOL TO REALISTICALLY CALCULATE COST AND WEIGHT BENEFITS ARISING FROM INCORPORATION OF SUCH MATERIALS</td>
</tr>
<tr>
<td>• ULTRA LIGHTWEIGHT AL ALLOYS</td>
<td>• PRIORITIZE AND SELECT FOR FUNDING THE SEVERAL MATERIALS THAT OFFER THE MOST SIGNIFICANT PAY-OFF IN THE 3-10 YEAR TIME FRAME</td>
</tr>
<tr>
<td>• METAL MATRIX COMPOSITES</td>
<td>• INSIST ON A TEAMING APPROACH THAT INCLUDES NASA, PRODUCERS AND USERS AND INVOLVES SELECTION, DESIGN, MANUFACTURING, AND ENGINEERING CRITERIA</td>
</tr>
<tr>
<td>• POLYMER BASED COMPOSITES</td>
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<tr>
<td>• DEVELOPMENT OF THESE MATERIALS TO MATURITY, AND APPLICATION IN NASA PROGRAMS, WILL HAVE A PROFOUND INFLUENCE ON WEIGHT AND COST SAVINGS AS WELL AS TECHNOLOGICAL IMPACT</td>
<td></td>
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DESCRIPTION:
• NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES

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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tbody>
<tr>
<td>• CURRENT VEHICLE SYSTEM STRUCTURES EMPLOY CONVENTIONAL MATERIALS AND FABRICATION TECHNOLOGY</td>
<td>• INITIATE AGGRESSIVE TECHNOLOGY DEVELOPMENT PROGRAM TO DEMONSTRATE FORMING AND JOINING PROCESSES SUITABLE FOR ALL APPROPRIATE VEHICLE SYSTEM STRUCTURES</td>
</tr>
<tr>
<td>• RESULTANT STRUCTURES ARE TYPICALLY HIGH COST AND WEIGHT PENALTIES ARE BUILT INTO THE DESIGN</td>
<td>• IDENTIFY VEHICLE STRUCTURES DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO NEAR NET SHAPE PROCESSING</td>
</tr>
<tr>
<td>• NUMEROUS NEAR NET SHAPE FABRICATION OPPORTUNITIES EXIST, EMPLOYING FORMING AND JOINING TECHNOLOGIES WHICH ARE RECOGNIZED, BUT REQUIRE DEVELOPMENT</td>
<td>• SELECT NEAR NET SHAPE PROCESSES AMENABLE TO VEHICLE HARDWARE</td>
</tr>
<tr>
<td>• PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION AND TOTAL PROGRAM COSTS</td>
<td>• DEVELOP CANDIDATE HARDWARE PROGRAM TO DEMONSTRATE/VALIDATE FABRICATION TECHNOLOGY</td>
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EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS  
VEHICLE SYSTEMS PANEL

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<th>DESCRIPTION:</th>
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<tr>
<td>• NDE OF ADVANCED STRUCTURES</td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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</thead>
<tbody>
<tr>
<td>• NEED AUTOMATED REAL-TIME TECHNIQUES TO REDUCE COST</td>
<td>• NDE PROCESSES TO EVALUATE INCLUDE:</td>
</tr>
<tr>
<td>• HIGHER-STRENGTH MATERIALS NEED MORE RELIABLE NDE</td>
<td>- REAL-TIME X-RAY</td>
</tr>
<tr>
<td>• FRACTURE TOUGHNESS DRIVEN DESIGNS REQUIRE PRECISE FLAW IDENTIFICATION/DETECTION</td>
<td>- REAL-TIME ULTRASONICS</td>
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<td></td>
<td>- ACOUSTIC EMISSION</td>
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<td></td>
<td>- EDDY CURRENT</td>
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<tr>
<td></td>
<td>• INCORPORATE AUTOMATION FEATURES</td>
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<td></td>
<td>• EVALUATE BUILT-IN SENSORS FOR COMPOSITES</td>
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<th>DESCRIPTION:</th>
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<tr>
<td>• ALL-U: TECHNOLOGY</td>
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<tr>
<td>• SPACE PROGRAMS REQUIRE UNIQUE LIGHT WEIGHT MATERIALS</td>
<td>• FUND GOVERNMENT, INDUSTRY, AND PRODUCER PROGRAM TO ACCELERATE NEAR-TERM AND FAR-TERM ALL-U DEVELOPMENT</td>
</tr>
<tr>
<td>• ALLOYS DEVELOPED FOR COMMERCIAL AND MILITARY AIRCRAFT NOT DIRECTLY APPLICABLE</td>
<td>• TAILOR MATERIALS DEVELOPMENT WITH SELECTED MANUFACTURING PROCESSES</td>
</tr>
<tr>
<td>• MATERIAL PRODUCERS ARE NOT CURRENTLY PLANNING TO INDEPENDENTLY DEVELOP THE REQUIRED LAUNCH VEHICLES ALLOYS. DEVELOPMENT WILL BE MARKET/USER DRIVEN</td>
<td></td>
</tr>
<tr>
<td>• NEAR-TERM ALL-U ALLOYS CAN PROVIDE UP TO 15 PERCENT WEIGHT SAVINGS. LONGER-TERM ALLOYS HAVE POTENTIAL WEIGHT SAVINGS UP TO 30 PERCENT</td>
<td></td>
</tr>
<tr>
<td>• ALL-U ALLOYS PROVIDE UNIQUE PROCESSING OPTIONS, I.E. SUPERPLASTIC FORMING</td>
<td></td>
</tr>
<tr>
<td>• LACK OF CODE R FUNDING LIMITS EFFECTIVENESS OF BRIDGING PROGRAM</td>
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</table>
BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

15% tank weight savings due to improved specific properties

80% raw material weight savings due to reduced scrap rate (80:20)

**Material costs**
- $1.0 M
- $4.2 M
- + $3.2 M

**Cost-to-orbit benefit**
- $100 M
- $85 M
- - $15 M

**System costs savings**
- + $3.2 M
- - $15.0 M
- - $11.8 M

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

**DESCRIPTION:**
- COMPOSITE TECHNOLOGY FOR CRYOTANKS AND DRY BAY STRUCTURES (WITH EMPHASIS ON FIBER REINFORCED PLASTIC SYSTEMS)

**MILESTONES & RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- PROCESSES MUST BE DEFINED TO ACCOUNT FOR FRP MANUFACTURING CAPABILITIES
- A TOTALLY INTEGRATED MATERIALS, DESIGN, MANUFACTURING, INSPECTION, AND TESTING PROCESS MUST BE IDENTIFIED WHICH WILL ACCOUNT FOR THE UNIQUE PROCESS NEEDS AND CAPABILITIES OF COMPOSITES
- WEIGHT REDUCTION POTENTIAL IS 20-30 PERCENT

**RECOMMENDED ACTIONS:**
- ESTABLISH COMPOSITE CRYOTANK SYSTEM DESIGN REQUIREMENTS; IDENTIFY LINER REQUIREMENTS
- DETERMINE STATE-OF-THE-ART CAPABILITIES IN FRP COMPOSITES FOR MATERIALS, DESIGN, MANUFACTURING, INSPECTION AND TESTING; SPECIFICALLY CONSIDER THE FOLLOWING:
  - IN-LINE INSPECTION
  - IN-SITU CURE METHODOLOGY
  - TOOLING APPROACH
  - JOINING TECHNOLOGY
  - COMPOSITE DAMAGE TOLERANCE AND REPAIR
- DESIGN A BASELINE CRYOTANK
- CONDUCT MANUFACTURING PROCESS TRADES
- ESTABLISH A BASELINE MANUFACTURING PROCESS
- DEFINE FACILITY SIZE REQUIRED TO SUPPORT FRP
MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

Cryotank

- Materials
  - Al-Li
  - SiCp/AI MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components

Benefits
- Advanced materials: 20-30% weight savings
  Increased payload
  Greater range
- Low cost fabrication: 30% cost savings
  Reduced assembly time
- NDE/durable materials: Increased reliability and vehicle life

Core primary structure

- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platings

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS VEHICLE SYSTEMS PANEL

DESCRIPTION:
- WELDING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- AUTOMATION POTENTIALLY CAN REDUCE NDE

RECOMMENDED ACTIONS:
- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS
### EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

#### VEHICLE SYSTEMS PANEL

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<td>- BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS</td>
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<tr>
<td>• INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%)</td>
<td>• IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH</td>
</tr>
<tr>
<td>• LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS</td>
<td>• DEVELOP FORMING AND JOINING PROCESS TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS</td>
</tr>
<tr>
<td>• BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES</td>
<td>• DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS</td>
</tr>
<tr>
<td>• PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST</td>
<td>• DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS</td>
</tr>
<tr>
<td></td>
<td>• VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTS OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES</td>
</tr>
</tbody>
</table>

### SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

- **THE MAJOR NEAR TERM ISSUE FOR AL-LI IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS**
  - Production capability is in place for 8090, Weldalite, and 2090
  - Near net shape processes have been defined and scale up activities are underway
  - Program management decisions are required to exploit potential

- **MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE**
  - No focused programs in materials and structures technologies within NASA for launch vehicles
  - Clear need for sustained/continuing programs to support user needs/long term NASA missions

- **SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS**

- **NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS**

- **JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS**
REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES
• FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
• CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL

MAJOR TECHNOLOGY CATEGORIES
- MATERIALS
- STRUCTURAL CONCEPTS
- FABRICATION/MANUFACTURING
- DESIGN/ANALYSIS/CERTIFICATION
- NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>STRUCTURAL CONCEPTS</th>
<th>FABRICATION/MANUFACTURING</th>
<th>DESIGN/ANALYSIS/CERTIFICATION</th>
<th>NDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• COMPOSITES</td>
<td>• NEAR NET SHAPES</td>
<td>• BOND</td>
<td>• CRITERIA</td>
<td>• DESIGN FOR INSPECTABILITY</td>
</tr>
<tr>
<td>• Al-Li</td>
<td>• INTEGRALLY-MACHINED</td>
<td>• WELD</td>
<td>• SYSTEMS OPTIMIZATION</td>
<td>• HEALTH MONITORING</td>
</tr>
<tr>
<td>• TPS</td>
<td></td>
<td>• EXTRUDE</td>
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<td></td>
<td></td>
<td>• FORGING</td>
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<td></td>
<td>• POWDER</td>
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<td></td>
<td></td>
<td>• LIQUID ATOMIZATION</td>
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DESCRIPTION:
• IN SPACE JOINING
  - WELDING
  - BONDING

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
• REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED
• IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES
• WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES
• SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR
• ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM

RECOMMENDED ACTIONS:
• IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE
• IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE
• DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE
• IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE
• DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS
• PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT
# REUSABLE VEHICLES SUBpanel

## Issue/Technology Requirements

<table>
<thead>
<tr>
<th>Description:</th>
<th>Milestones &amp; Resource Requirements:</th>
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<tbody>
<tr>
<td>• Damage Tolerant Design for Composite Structures</td>
<td>• Publish Damage Tolerant Design Data Book for Composite Structure</td>
</tr>
</tbody>
</table>

### Background & Related Factors:

- Space Transportation Missions Are Weight Driven
- Composites Reduce Weight, Reduce Part Count and Are Adaptable to Complicated Shapes
- Unless Properly Designed, Easily Damaged
- Goal: Visually Inspect Only with Minimal Impact on Weight

### Recommended Actions:

- Develop Damage Tolerant Philosophy/Criteria
- Assemble Industry Available Test Data
- Identify Candidate Fibers, Resins, Lay-Ups, and Manufacturing Processes for Damage Tolerant Skin Designs
- Develop Designed Experiment Utilizing Damage Tolerant Testing to Identify Drivers (Temperature Range R.T. to 800°F)
- Utilize Best Skin Designs for Honeycomb Panels and Perform Designed Experiment to Again Identify Drivers (Temperature Range R.T. - 800°F)

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<tr>
<td>• Optimized System Engineering Approach to Ensure Robustness</td>
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</tbody>
</table>

### Background & Related Factors:

- Low Margins in the Ascent Operational Envelope Increases Operational Cost
- Maintenance and Refurbishment of Low-Life Parts Is Costly in Inspection, Analysis and Change-Out
- Robustness Provides Lower Total Cost, Less Rework, Launch Time, Higher Performance and Less Complex Operation

### Recommended Actions:

- Develop Concurrent Engineering Tools for Flight Mechanics, Control, Performance, Loads, Aeroelasticity, Manufacturing, Operations, etc...
- Develop Inter-Disciplinary, Total Cost Optimization and Trades Analysis Tools
- Develop Accurate Statistical Quantification Tools for All Sensitive Parameters
- Develop Atmospheric (Winds) Characteristics for Design and Operation
- Analytical Tools to More Accurately Predict Aerodynamics, Plumes, Acoustical, etc. Induced Environment Data CFD
- Develop Model Synthesis Tools to Reduce Model Development
- Develop System Probabilistic Tools to Guide Optimization Criteria
### REUSABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

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<td>• MAINTENANCE AND REFURBISHMENT PHILOSOPHY</td>
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<tbody>
<tr>
<td>• CURRENT REUSABLE SPACE VEHICLES ARE ESSENTIALLY DE-CERTIFIED AS FLIGHT VEHICLES AT THE MOMENT OF TOUCHDOWN</td>
<td>• EXAMINE MAINTENANCE AND REFURBISHMENT PHILOSOPHIES OF NON-SPACE VEHICLE OPERATORS TO IDENTIFY &quot;LESSONS LEARNED&quot; FOR SPACE SYSTEMS</td>
</tr>
<tr>
<td>• RE-CERTIFICATION REQUIRES LARGE SCALE D ISASSEMBLY, INSPECTION, AND TEST PRIOR TO NEXT FLIGHT</td>
<td>• DEFINE EXPERIENCE DATA BASE FROM PAST REUSABLE VEHICLE FLIGHTS TO ALLOW STATISTICAL CORRELATION OF SYSTEM FAILURE MODES, EFFECTS, AND FREQUENCIES WITH MAINTENANCE AND REFURBISHMENT APPROACHES</td>
</tr>
<tr>
<td>• THESE ACTIVITIES ARE LABOR INTENSIVE AND ACCOUNT FOR A LARGE PART OF THE OPERATIONS COST OF THE VEHICLE.</td>
<td>• DEVELOP CRITERIA TO DESIGN FOR MAINTENANCE AND ASSEMBLY</td>
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<td></td>
<td>• IDENTIFY MAINTENANCE AND REFURBISHMENT REQUIREMENTS FOR PROPOSED VEHICLE TECHNOLOGIES</td>
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<td></td>
<td>• COORDINATE TEST PHILOSOPHY AND STRUCTURAL/DESIGN CRITERIA EFFORTS (E.G., DESIGN FOR ASSEMBLY/REPAIR APPROACHES)</td>
</tr>
</tbody>
</table>

### TECHNOLOGIES

• ADVANCED STRUCTURAL MATERIALS
• AL-LI TECHNOLOGY
• NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES
• NEAR NET SHAPE METALS TECHNOLOGY
• NEAR NET SHAPE EXTRUSIONS FOR STRUCTURAL HARDWARE
• NEAR NET SHAPE: FORGINGS
• NEAR NET SHAPE: SPIN FORGINGS
• WELDING
• IN-SPACE WELDING/JOINING
• COMPOSITES TECHNOLOGY FOR CRYOTANKS AND DRYBAY STRUCTURES
• JOINING TECHNOLOGY FOR COMPOSITE CRYOTANKS
• TOOLING APPROACH FOR MANUFACTURING LARGE DIAMETER CRYOTANKS
• DEVELOP A CURE METHODOLOGY FOR LARGE COMPOSITE CRYOTANKS
• STATE-OF-THE-ART BUCKLING STRUCTURE OPTIMIZER PROGRAM
• STATE-OF-THE-ART "SHELL OF REVOLUTION" ANALYSIS PROGRAM
• NDE FOR ADVANCED STRUCTURES
• IN-LINE INSPECTION OF COMPOSITES
• SCALE-UP OF LAUNCH VEHICLES
• LAUNCH VEHICLE TPS/INSULATION BEYOND 27.5 FT. DIAMETER
• DESIGN & FABRICATION OF THIN WALL CRYOTANKS FOR SPACE EXPLORATION (5-20 FT. DIA.)
7.1.2 Supporting Charts
### Reusable Vehicles Subpanel
Vehicle Systems Panel

<table>
<thead>
<tr>
<th>Description:</th>
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<tr>
<td>• Cryogenic tankage</td>
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<tr>
<td>• Qualify Al-Li tankage</td>
<td>• Sufficient data base for program managers to accept the material in new launch vehicle programs</td>
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<tr>
<th>Background &amp; Related Factors:</th>
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<tr>
<td>• Lightweight cryogenic tanks will increase the payload to orbit of various launch systems</td>
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<tr>
<td>• Al-Li has not reached the maturity to incorporate into the design without considerable additional effort beyond that currently funded.</td>
<td>• Conduct a program coordinated with existing programs to ensure that the necessary technology has been demonstrated and that engineering properties including Al-H3K-5 statistically derived parent material and weld properties, fracture toughness, stress corrosion, resistance, etc. have been established</td>
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<td>• Cryogenic tankage</td>
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<tr>
<td>• Qualify composite tankage for use with liquid hydrogen</td>
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<th>Recommended Actions:</th>
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</thead>
<tbody>
<tr>
<td>• Greater payload to orbit can be obtained with composite tanks suitable for use with liquid hydrogen</td>
<td></td>
</tr>
<tr>
<td>• Recent tests with a 1/3 full scale NASP tank with liquid nitrogen (LN2) demonstrated that the composite was not permeable at LN2 temperatures. Earlier small scale tests with gaseous helium at -420F demonstrated technically acceptable permeability and resistance to microcracking when thermally cycled. NASP 1/3 scale tank is currently in test. Thermal cycle tests and liquid hydrogen loading are being conducted.</td>
<td>• Establish the enabling technology to build, insulate and test a sub-scale tank. Tank test successful</td>
</tr>
</tbody>
</table>

| identified where the technology is adequate and where development is required  |
| • Demonstrate adequate technology  |
| • Develop technology (subscale)  |
| • Decide on manufacturing approach  |
| • Design subscale tank with all the features of a full scale tank  |
| • Fabricate, insulate, inspect and test tank with LH2 |
### Reusable Vehicles Subpanel

#### Vehicle Systems Panel

<table>
<thead>
<tr>
<th>Description:</th>
</tr>
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</table>
| • Cryogenic tankage  
  • Qualify composite tankage for use with liquid oxygen |

<table>
<thead>
<tr>
<th>Milestones and Resource Requirements:</th>
</tr>
</thead>
</table>
| • Demonstrate the ability to meet safety requirements  
  • Feasibility program $500k |

<table>
<thead>
<tr>
<th>Background &amp; Related Factors:</th>
</tr>
</thead>
</table>
| • Greater payload to orbit can be obtained with composite tanks suitable for use with LOX  
  • Recent tests with a 1/3 full scale NASP tank with liquid nitrogen (LN2) demonstrated that the tank was not permeable (in an engineering sense) at LN2 temperatures. NASP 1/3 subscale tank is currently in test. Thermal cycle tests and liquid hydrogen loading are being conducted. |

<table>
<thead>
<tr>
<th>Recommended Actions:</th>
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</table>
| • Establish feasibility program with the following as a minimum:  
  • Establish set of design ground-rules  
  • Develop liners with damage that will prevent a conflagration  
  • Tests to demonstrate no conflagration  
  • 1000 cycles of rapid O2 pressurization  
  • Conduct rapid fill with particle impingement  
  • Burst test |

### Launch Vehicle TPS/Insulation

<table>
<thead>
<tr>
<th>Description:</th>
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<tbody>
<tr>
<td>• Launch vehicle TPS/insulation</td>
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<table>
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<tr>
<th>Milestones and Resource Requirements:</th>
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</table>

<table>
<thead>
<tr>
<th>Background &amp; Related Factors:</th>
</tr>
</thead>
</table>
| • Clean Air acts mandate eliminations of Freon blowing agents  
  • Robust design philosophy dictates durable TPS systems  
  • Long duration space missions require space qualified TPS materials to survive environment and not create debris for other critical operations |

<table>
<thead>
<tr>
<th>Recommended Actions:</th>
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</thead>
</table>
| • Continue APS to develop alternate blowing agents  
  • Look beyond near-term fixes to fund long-term replacement materials  
  • Develop robust/reusable or easily replaceable TPS |
<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DURABLE PASSIVE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
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<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• REUSABLE CVT PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURN AROUND</td>
<td>• DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN AH-LI</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• THE ANISOTROPY OF AH-LI ESPECIALLY THE REDUCED STRENGTH IN THE SHORT TRANSVERSE DIRECTION SIGNIFICANTLY IMPACTS THE UTILITY OF AH-LI APPLICATIONS</td>
<td>• REFINEx EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOTROPIC AH-LI</td>
</tr>
<tr>
<td>• DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM AH-LI USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE AH-LI BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISOTROPY</td>
<td>• SUPPORT SCALE-UP OF LAB PROCESS TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES</td>
</tr>
<tr>
<td>• CHARACTERIZE MATERIAL PROTOTYPES OF AH-LI PRODUCED BY THESE METHODS</td>
<td></td>
</tr>
</tbody>
</table>
# REUSABLE VEHICLES SUBPANEL

## VEHICLE SYSTEMS PANEL

### DESCRIPTION:
- DURABLE THERMAL PROTECTION SYSTEM (TPS)

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- FUTURE REUSABLE VEHICLE PROGRAMS REQUIRE LIGHTWEIGHT/DURABLE TPS FOR MINIMUM COST AND QUICK TURN AROUND
- DURABILITY FOR WIND/RAIN AND SERVICING OPERATIONS IS REQUIRED
- MECHANICALLY ATTACHABLE TPS CAN PROVIDE ACCESS FOR INSPECTION AND REPLACEMENT
- TPS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE DOES NOT EXIST

### RECOMMENDED ACTIONS:
- CONTINUE DEVELOPMENT OF DURABLE BOND-ON CERAMIC TILES
- CONTINUE DEVELOPMENT OF DURABLE MECHANICALLY ATTACHABLE METALLIC AND CERAMIC DESIGNS
- DEVELOP HIGH TEMPERATURE ADHESIVES FOR BOND-ON DESIGNS
- DEVELOP SPECIFIC TPS DESIGNS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE INCLUDING HIGH STRENGTH & TEMPERATURE FOAM INSULATION: MAY INVOLVE GROUND PURGE SYSTEM
- DEMONSTRATE SUITABILITY OF DESIGNS BY FABRICATION AND TESTING TO APPROPRIATE WIND/RAIN, ACOUSTIC, AEROPRESSURE, THERMAL REQUIREMENTS

### DESCRIPTION:
- UNPRESSURIZED ALI STRUCTURES (INERTSTAGES, THRUST STRUCTURES)
  - QUALIFY ALI FOR USE WITH UNPRESSURED VEHICLE AND STABILITY LIMITED STRUCTURES

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- MAJOR PORTIONS OF VEHICLE STRUCTURES ARE STABILITY LIMITED. THESE INCLUDE COMPRESSION AND BENDING LOADED STRUCTURES. ALI ALLOYS OFFER INCREASED IN SPECIFIC STIFFNESS OF 20-40% OVER CURRENT ALUMINUM ALLOYS, WITH THE POTENTIAL FOR CORRESPONDING WEIGHT SAVINGS IN THESE STRUCTURES

### RECOMMENDED ACTIONS:
- FUND DEVELOPMENT AND TESTING OF DEMONSTRATION OF STABILITY LIMITED STRUCTURES (THRUST STRUCTURES, INTERTANK CONNECTORS, WING BOXES)
- COORDINATE WITH LOW COST MANUFACTURING AND NEAR NET SHAPE ACTIVITIES
## Description:
- Near net shape sections
  - Extrusions
  - Forgings

## Background & Related Factors:
- Cost of scrap metal on integrally machined hardware is not cost effective for newer metal alloys
- Recent advances in roll forging and incremental forging offer significant material cost and part count reductions for launch vehicles
- Process parameters need to be developed for each new alloy

## Recommended Actions:
- Identify candidate hardware for large extrusions, roll and incremental forging processes
- Develop candidate hardware to demonstrate/validate fabrication technology
- Generate design allowables

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## Description:
- Pressurized structures

## Background & Related Factors:
- Pressurized structures commonly used as crew compartments on Shuttle and Space Station are currently fabricated from conventional materials.
- New applications such as NASP, SSTO, and MTV will have greater demands to reduce weight while being subjected to harsher environments
- Advanced materials such as AHU and/or composites have properties conducive to the above requirements. Integral skin and stringer, sandwich panels, etc. are all designs where these materials would prove advantageous

## Recommended Actions:
- Continue development of design criteria for these structures
- Conduct development tests to determine the applicability of these materials to meet the requirements
- Design and fabricate test articles to verify the approach
### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

**DESCRIPTION:**
- WELDING AND JOINING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

**MILESTONES AND RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING
- HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS
- LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES
- WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE
- AUTOMATION POTENTIALLY CAN REDUCE NDE

**RECOMMENDED ACTIONS:**
- IDENTIFY PROCESS VARIABLES RELATIONSHIPS
- DEVELOP PROCESS MODELS
- IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK
- IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE
- VERIFY AND VALIDATE PROCESSES AND CONTROLS
- DEVELOPMENT OF TELEROBOTIC CAPABILITY FOR ON-ORBIT REPAIR/MAINTENANCE/INSPECTION

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**DESCRIPTION:**
- MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS

**MILESTONES AND RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- THE THREAT TO SPACE VEHICLES FROM ORBITAL DEBRIS HAS BEEN RAPIDLY INCREASING
- CURRENT ALUMINUM DOUBLE-BUMPER SHIELDING IS VERY HEAVY AND NEWER SYSTEMS SUCH AS NEXTEL HAVE NOT BEEN QUALIFIED

**RECOMMENDED ACTIONS:**
- DEVELOP AND QUALIFY LIGHTWEIGHT SHIELDS AND ATTACHMENT TECHNIQUES
- CONDUCT A PROGRAM TO EVALUATE LIGHTWEIGHT SHIELDING DESIGNS TO MEET THE THREAT REQUIREMENTS
- ESTABLISH AND VERIFY ANALYTICAL MODELS, GOAL IS TO MINIMIZE SECONDARY EJECT AS WELL AS DEVELOP AND QUALIFY AN ULTRA-LIGHTWEIGHT SHIELDING DESIGN
### REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

#### DESCRIPTION:
- State-of-the-art shell buckling structure optimizer program to serve as a rapid design tool

#### MILESTONES AND RESOURCE REQUIREMENTS:

#### BACKGROUND & RELATED FACTORS:
- Current emphasis on development of large complicated finite element programs suited to detailed analysis, not design optimization
- Available codes are out of date, not comprehensive and user unfriendly
- Will improve the quality and speed of both preliminary design and detailed design

#### RECOMMENDED ACTIONS:
- Provide following features:
  - Macintosh or Windows user interface with graphic displays and pull-down menus
  - Simple user format designed for use by both design and analysis disciplines
  - Complete library of stiffened shell configurations

---

### DESCRIPTION:
- Test philosophy
  - Restrict structural test to a load factor that allows alternate usages of expensive hardware
  - No test factor

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Hardware has been tested to destruction or yield to the point where it is unusable for other applications
- Structures of advanced materials present significant cost to programs
- "No test factor" may be used as an alternate where weight may not be critical

### RECOMMENDED ACTIONS:
- Develop a test code that restricts test to loads which maximize the structures' "reusability." Independent tests should be conducted that allow for data extrapolation from the lower loads to qualify hardware.

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# REUSABLE VEHICLES SUBPANEL

## VEHICLE SYSTEMS PANEL

### DESCRIPTION:
- REDUCED LOAD CYCLE TIME

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- LONG TURNAROUND TIME LOAD CYCLES GREATLY INCREASES COST AND RESTRICTS IMPLEMENTATION OF NEEDED CHANGES
- LOAD CYCLE COSTS ARE EXCESSIVE

### RECOMMENDED ACTIONS:
- PROVIDE AN INTERDISCIPLINARY LOADS ANALYSIS TOOL THAT OUTPUTS LOADS AND STRESS INSTEAD OF SEQUENTIAL LOADS AND STRESS ANALYSIS
- DEVELOP MODEL SYNTHESIS TECHNIQUES TO REDUCE MODEL DEVELOPMENT
- DEVELOP AN OPTIMIZED CODE TO REDUCE COMPUTER COST

### DESCRIPTION:
- STRUCTURAL ANALYSIS METHODS

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- CURRENT ANALYSIS METHODS INVOLVE ANALYSIS BEING CONDUCTED BY ISOLATED GROUPS AND DISTRIBUTING RESULTS TO NEXT GROUP IN A SERIAL FASHION
- ITERATIONS ARE LONG AND LABORIOUS
- ANALYTICAL METHODS, PARTICULARLY IN THE AREA OF STABILITY KNOCK-DOWN FACTORS, SHOULD BE REVIEWED, UPDATED AS NECESSARY AND NORMALIZED

### RECOMMENDED ACTIONS:
- DEVELOP ELECTRONICALLY INTERFACED, SELF-CHECKING, AERO-DYNAMIC, THERMODYNAMIC, DYNAMIC & STRESS ANALYSIS TOOLS THAT ALLOW RAPID ITERATION AND APPLY THE BENEFITS OF CONCURRENT ENGINEERING
- REVIEW AVAILABLE DOCUMENTATION ON STABILITY ANALYSIS DERIVING CONCURRENCE ON KNOCK-DOWN FACTORS TO BE USED IN ABOVE ANALYSIS
- TEST AS REQUIRED
### REUSABLE VEHICLES SUBPANEL
### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Optimization of Structural Criteria</td>
<td></td>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Current Structural Criteria does not allow assessment of vehicle risk as related to load variability, Subsystem redundancy and factor of safety</td>
<td>• Develop simple probabilistic approach with necessary data to derive and justify structural criteria</td>
</tr>
<tr>
<td>• Lack of simple probabilistic approach to risk assessment stifles examination of required factor of safety to meet program objectives</td>
<td>• Develop analysis tools to implement structural reliability approach and selection of factors of safety</td>
</tr>
<tr>
<td>• Current approach is to use F.S. ≥ 1.25 for unmanned and F.S. ≥ 1.4 for manned systems</td>
<td></td>
</tr>
</tbody>
</table>

### DESCRIPTION:

<table>
<thead>
<tr>
<th>DEVELOP AN ENGINEERING APPROACH TO PROPERLY TRADE MATERIAL AND STRUCTURAL CONCEPTS SELECTION, FABRICATION, FACILITIES, AND COST (TOTAL COST)</th>
</tr>
</thead>
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<th>BACKGROUND &amp; RELATED FACTORS:</th>
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</tr>
</thead>
<tbody>
<tr>
<td>• Structural simplicity reduces assembly cost and operational cost</td>
<td>• Develop concurrent engineering tools (all disciplines) that properly trade between material, structural concept, fabricating facilities, performance, and operation</td>
</tr>
<tr>
<td>• Processing can increase cost, Mr Hardware, and lower margins (sensitivities)</td>
<td>• Develop optimization criteria for total cost</td>
</tr>
<tr>
<td>• Total cost is the driver, not just weight</td>
<td></td>
</tr>
<tr>
<td>• Sequential engineering is costly</td>
<td></td>
</tr>
<tr>
<td>• Sequential engineering tends to hide sensitivities and proper trades</td>
<td></td>
</tr>
</tbody>
</table>

| MILESTONES AND RESOURCE REQUIREMENTS: | |
|---------------------------------------| |
|                                       | |

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7.2 PROPULSION SYSTEMS PANEL
7.2.1 Final Presentation